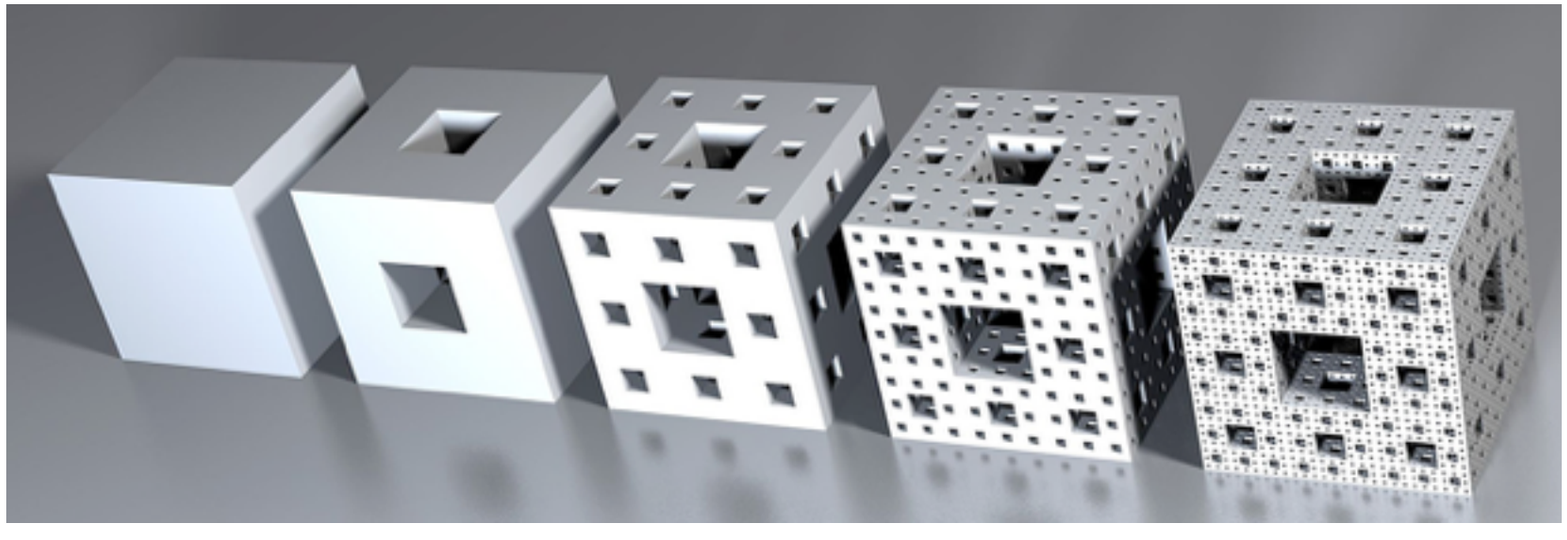
Light Composite Scalars

George T. Fleming
Yale University
(for the LSD Collaboration)

Lattice for BSM Physics
ALCF ANL



Composite Higgs Boson?

- Typically, UV-complete theories of composite Higgs bosons start with technicolor-like EWSB mechanism.

- In generic technicolor, the Higgs VeV is associated with the techni-pion decay constant: $v \sim f_{\pi T} \sim 250$ GeV.

- If the technicolor theory is like QCD, the composite Higgs boson is very heavy ($4.3\text{-}6.0\ f_{\pi T} \sim 1.1\text{-}1.5$ TeV) broad resonance.

- Viable composite Higgs models must have different dynamics to produce light, narrow Higgs boson.

- Studying the strong sector in isolation is an important first step but doesn't guarantee a viable Higgs replacement since SM dynamics should have a big effect on the Higgs sector: e.g. top quark corrections to Higgs mass.

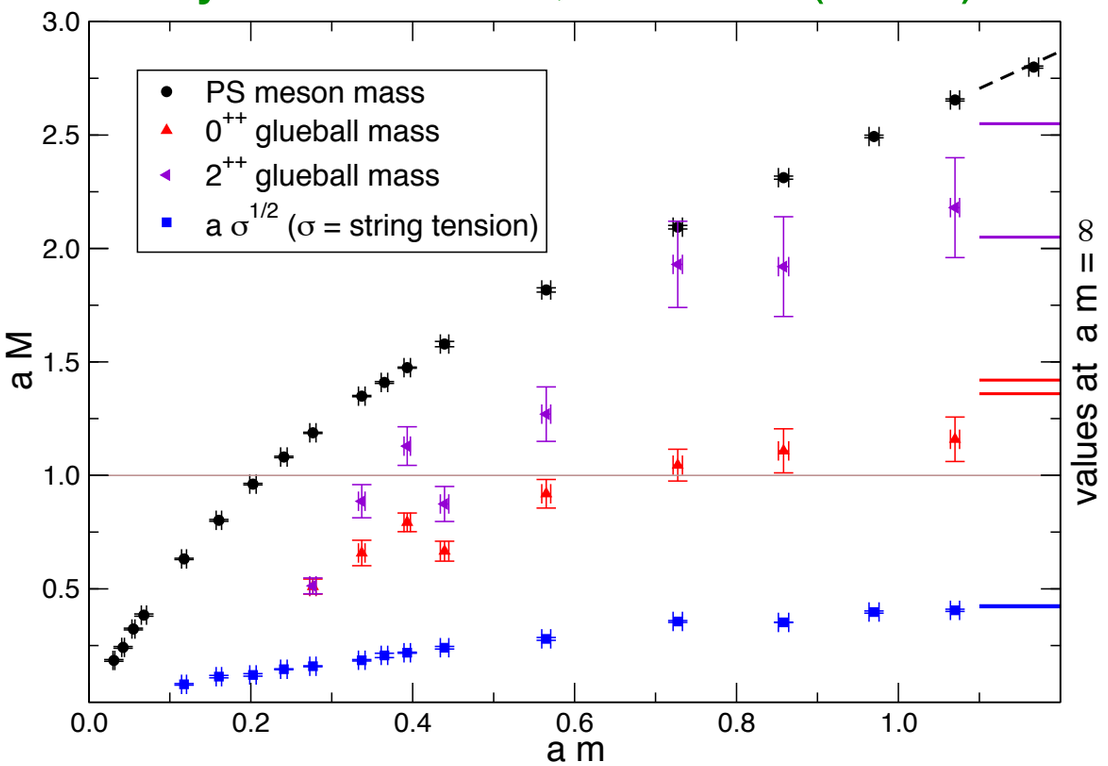
Light Scalars inside Conformal Window

- Mass-deformed IRFP theories seem to have very light scalars.

SU(2) N_f=2 adj

Edinburgh group

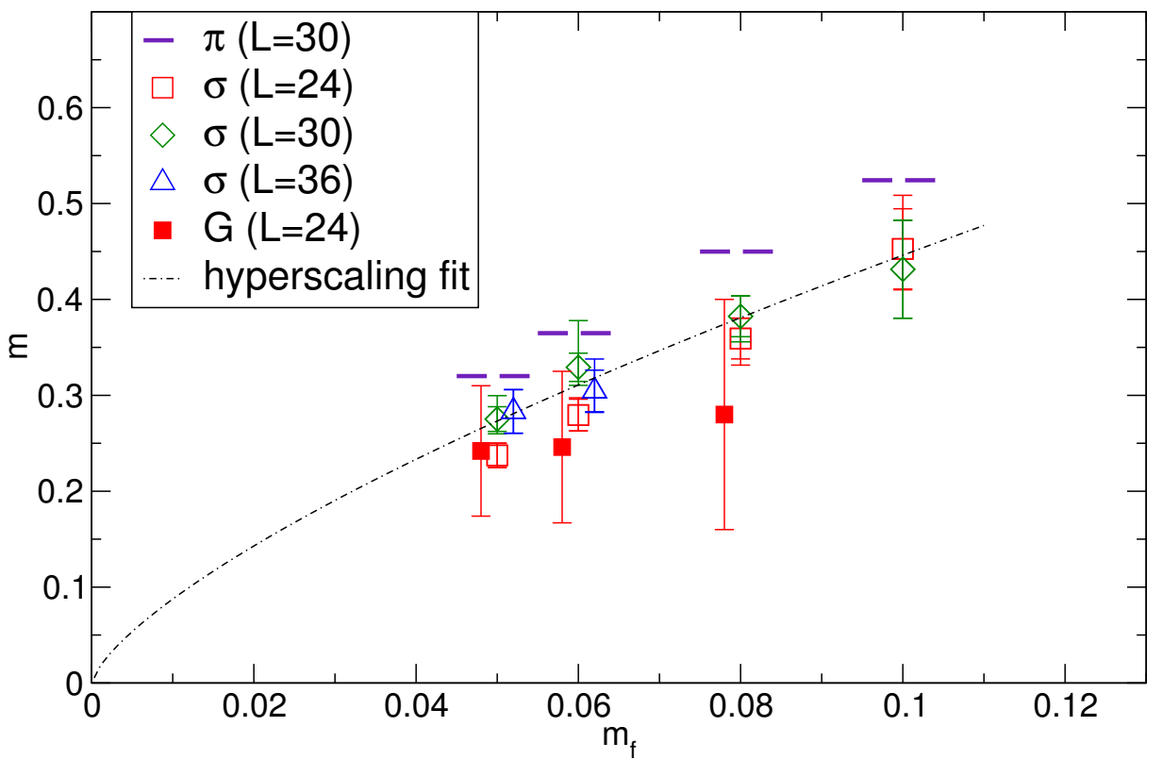
Phys. Rev. D 82, 014510 (2010)



SU(3) N_f=12 fund

LatKMI

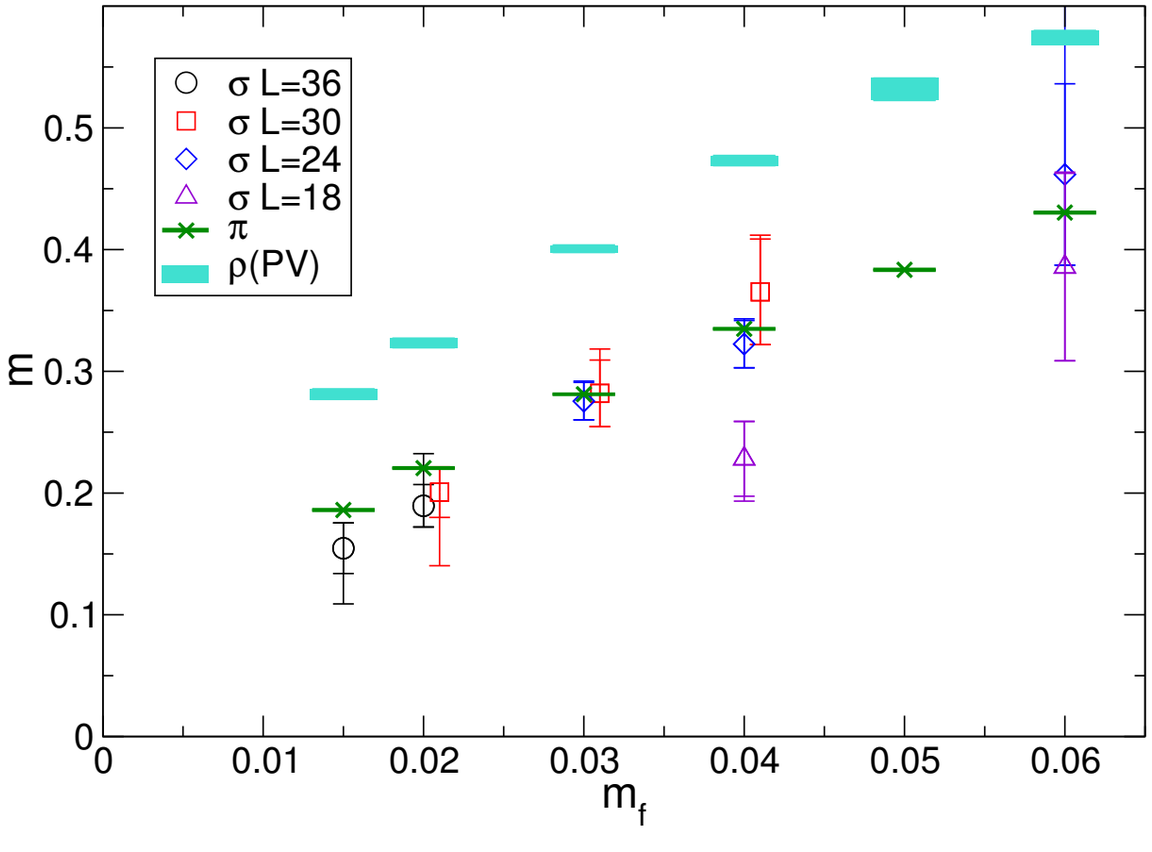
Phys. Rev. Lett. 111, 162001 (2013)



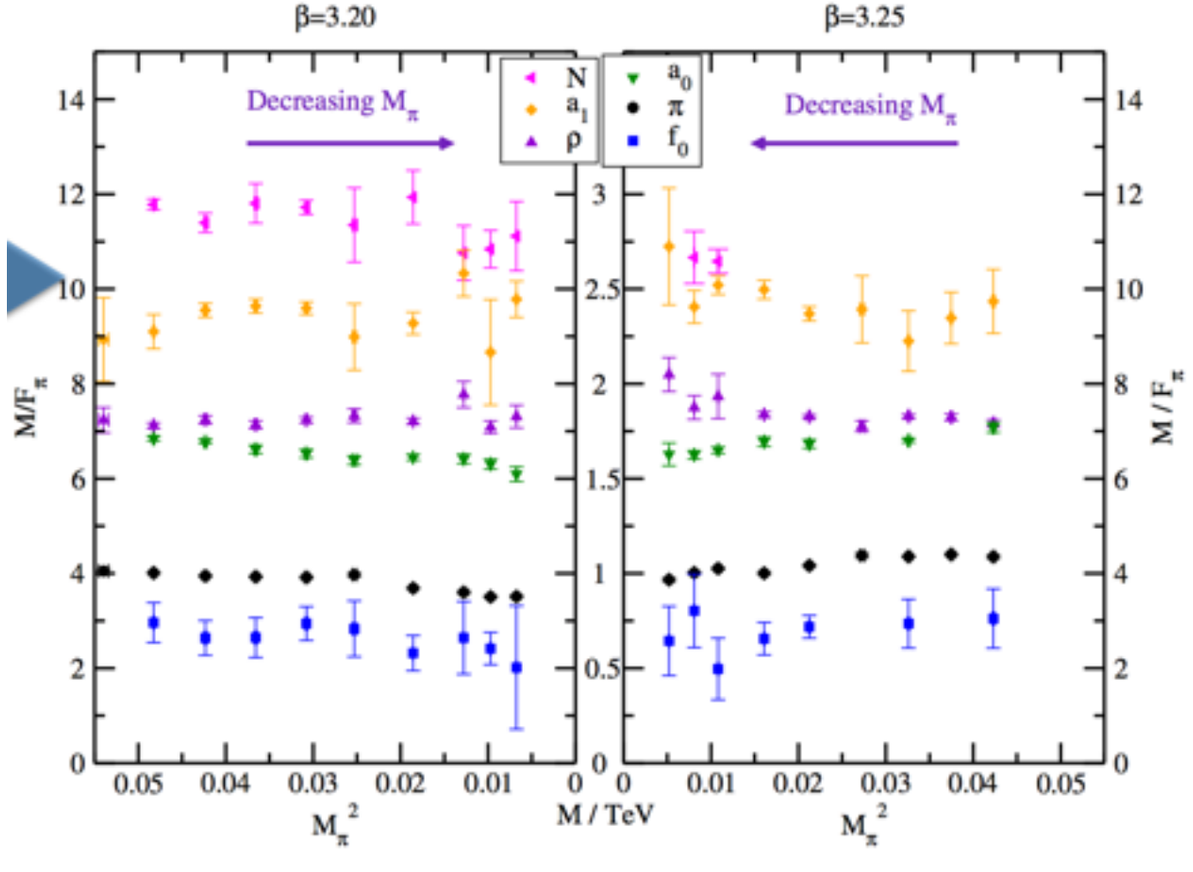
Light Scalars near Conformal Window

- Theories likely just outside conformal window also have light scalars.

SU(3) N_f=8 fund
LatKMI (Nagoya)
Phys. Rev. D 89, 111502 (2014)



SU(3) N_f=2 sym
L_{at}HC Collaboration
LATTICE 2015



Naive Argument Failing?

- Broad, heavy scalars do not seem to be a generic feature of confining, chirally-broken gauge theories.

- Instead, near-conformal theories might generically have light scalars (true in every case so far).

- How sure are we that SU(3) N_f=8 is not inside the conformal window?

- How sure are we that $M_\sigma \sim f_\pi$ in chiral limit?

Lattice Strong Dynamics Collaboration

James Osborn
Xiao-Yong Jin

Anna Hasenfratz
Ethan Neil

Graham Kribs

Richard Brower
Claudio Rebbi
Evan Weinberg

Oliver Witzel

Ethan Neil
Sergey Syritsyn

Meifeng Lin

Evan Berkowitz
Michael Buchoff
Enrico Rinaldi
Chris Schroeder
Pavlos Vranas

David Schaich

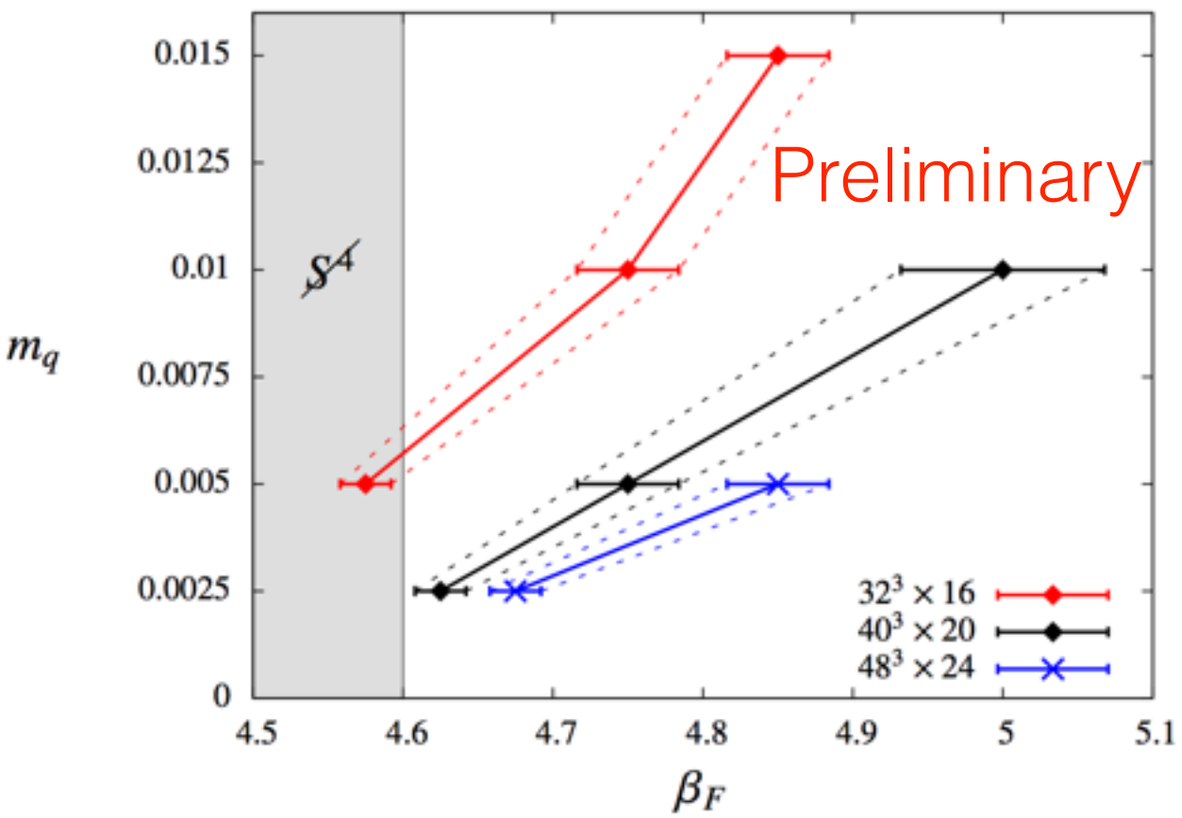
Joe Kiskis

Tom Appelquist
George Fleming
Andy Gasbarro

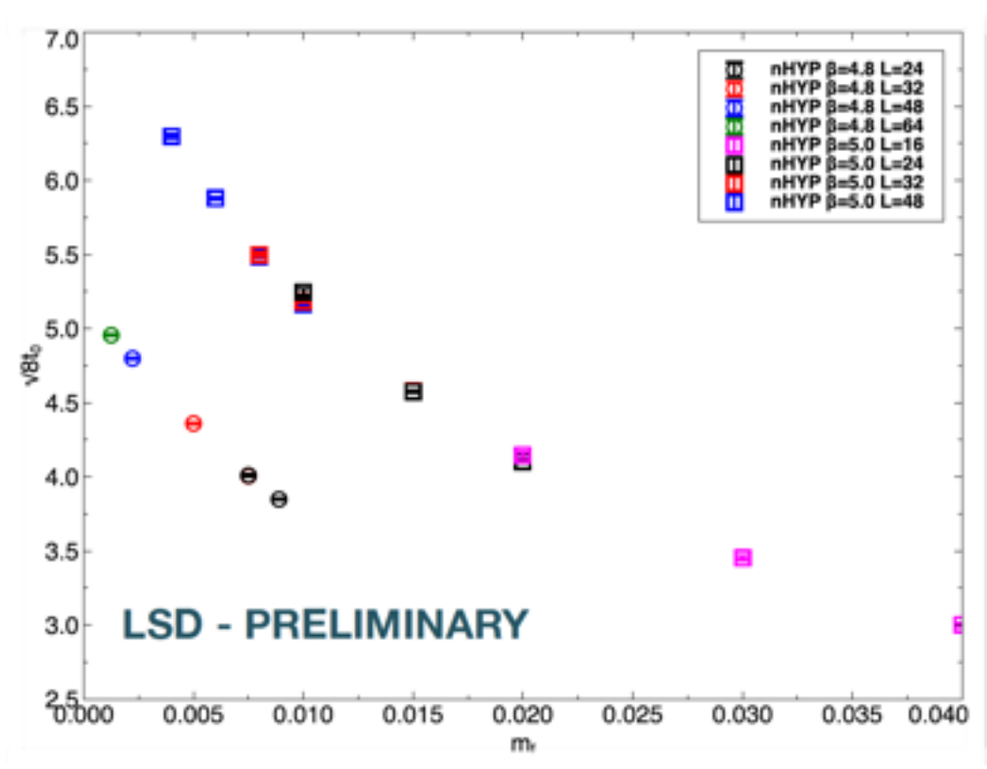
LSD SU(3) N_f=8 Stag

- Earlier USBSM studies (and LatKMI) used HISQ fermions which become prohibitively expensive for N_f=8 on coarse lattices.

- Now using nHYP stag fermions and fund+adj gauge action pioneered by Boulder group to get to somewhat coarser lattices.



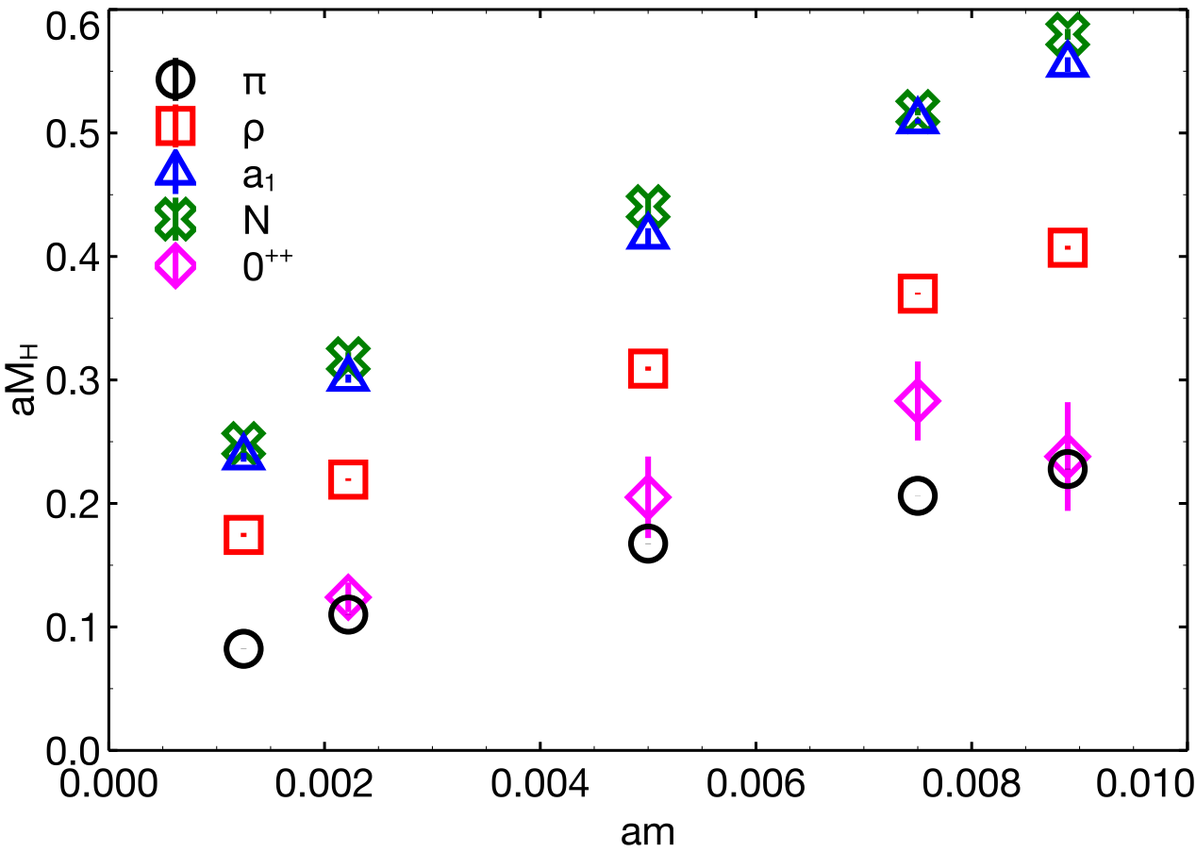
T_c and bulk phase

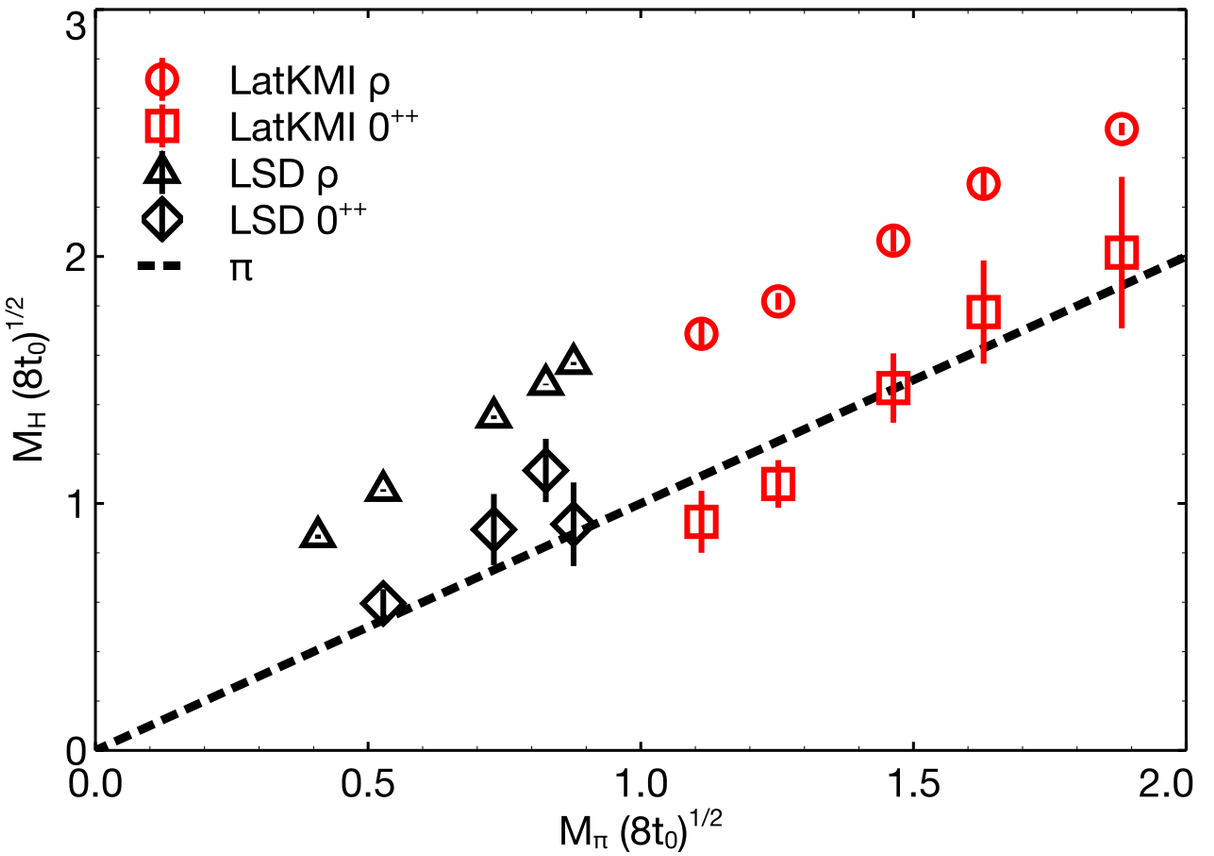


$\langle t^2 E(t) \rangle = 0.3$ @ $t=t_0$

Light hadron spectrum

- Spectrum consistent with earlier LSD N_f=8 results but at lighter quark mass.
- Very strong quark mass dependence.
- Submitted to PRL (arXiv:1601.04027)

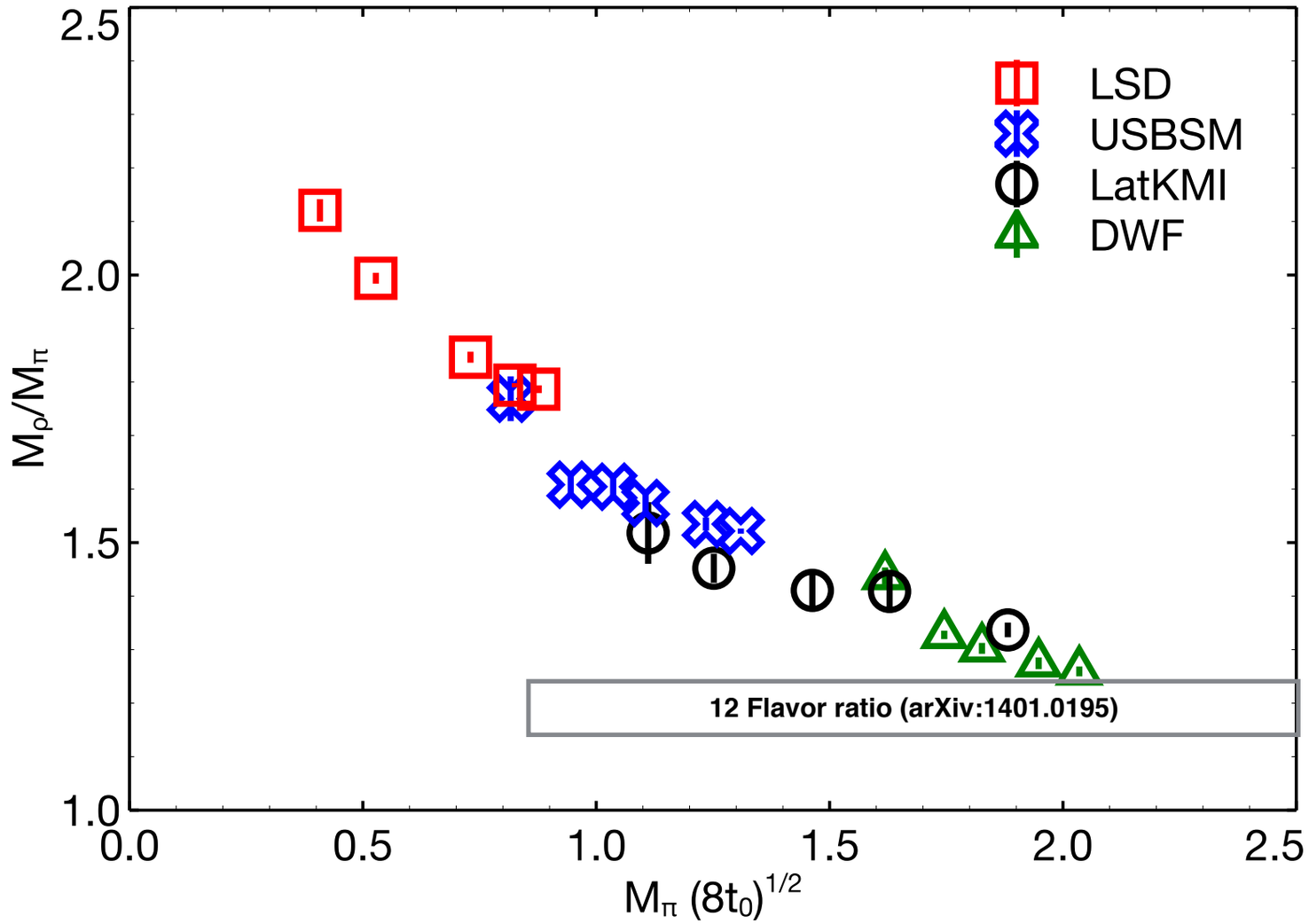




Not hyperscaling

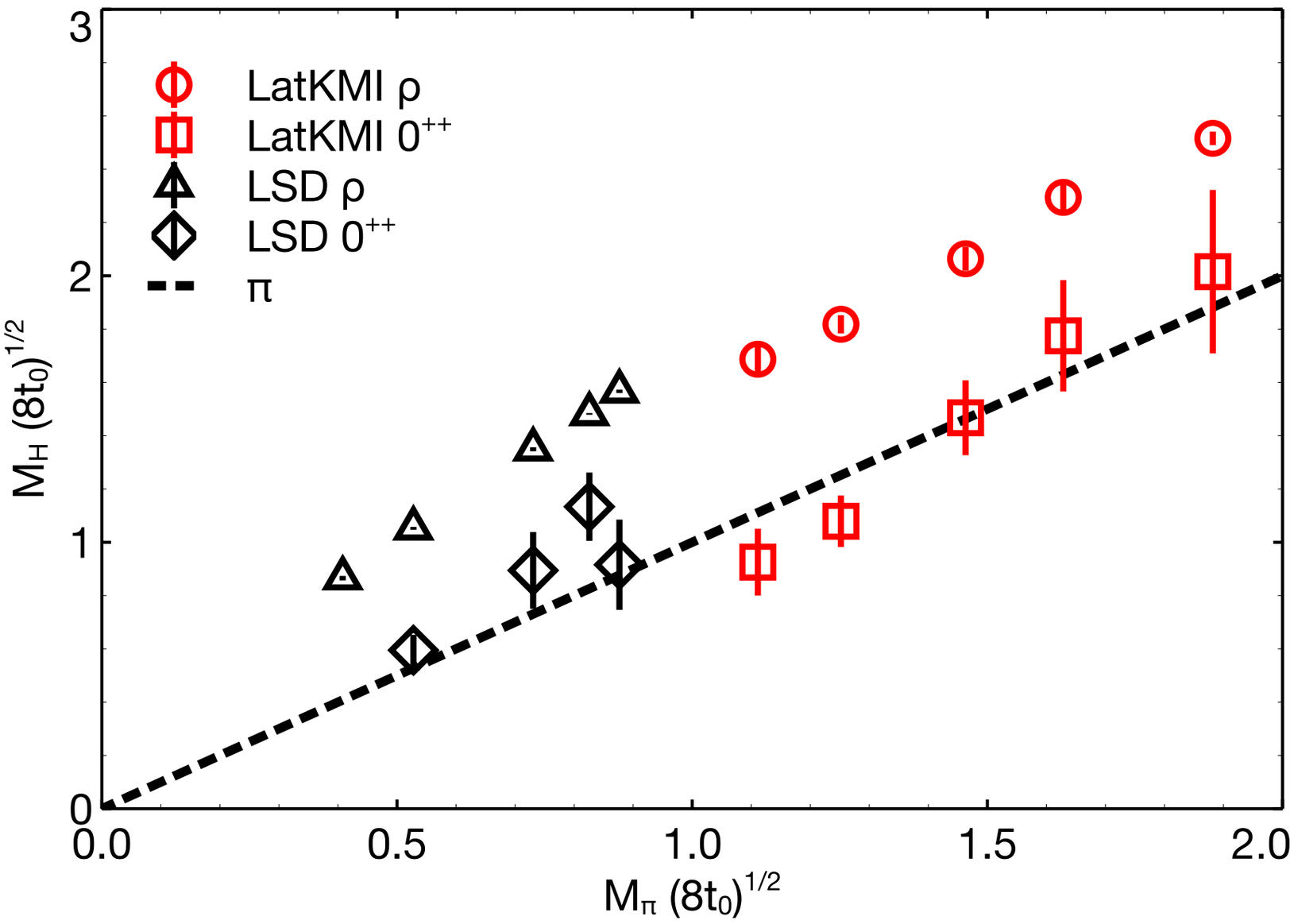
- Mass-deformed IRFP theories have hadron masses which scale in constant ratios in approach to conformity: $M_\rho/M_\pi \sim$ const as $M_\pi \to 0$.

- Pretty clear evidence that $N_f=8$ is outside conformal window since pion is becoming light relative to rho meson. Very different from $N_f=12$.



Isosinglet spectrum

- Stable scalar degenerate with pion even when $M_\pi/M_\rho \lesssim 1/2$.
- Submitted to PRL (arXiv:1601.04027)



Sophisticated Argument Against Composite Higgs

- OK, we found some theories with composite light scalars. Why should the couplings between π's and σ have any relation to h coupling to W,Z?

- i.e. construct χPT_S [Soto, Talavera and Tarrús, NPB **866**, 270 (2013)]

$$\mathcal{L}^{(2)} = \left(\frac{F^2}{4} r_{0d} + F r_{1d} S + r_{2d} S^2 + \cdots\right) \langle D_\mu U D^\mu U^\dagger \rangle + \left(\frac{F^2}{4} r_{0m} + F r_{1m} S + r_{2m} S^2 + \cdots\right) (\langle \chi^\dagger U + \chi U^\dagger \rangle - \langle \chi^\dagger + \chi \rangle),$$

- Of course, we have to drop by hand scalar self interactions

$$\mathcal{L}^S = \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{1}{2}\mathring{m}_S^2 S S - \lambda_1 S - \frac{\lambda_3}{3!} S^3 - \frac{\lambda_4}{4!} S^4 + \cdots$$

- When matched to your theory, why should O(1) LECs look anything like the SM Higgs (i.e. the linear sigma model)?

Reverse-Engineering EFTs

- On the lattice, we have access to the UV-complete theory so let's just compute the relevant quantities:
  - I=0,1,2 pi-pi scattering
  - pi-sigma scattering
  - sigma-sigma scattering
  - scalar form factors
- OK, it's hard, but not as hard as it seems. Remember the sigma is a stable meson as light as the pion.

Width of Vector Resonance

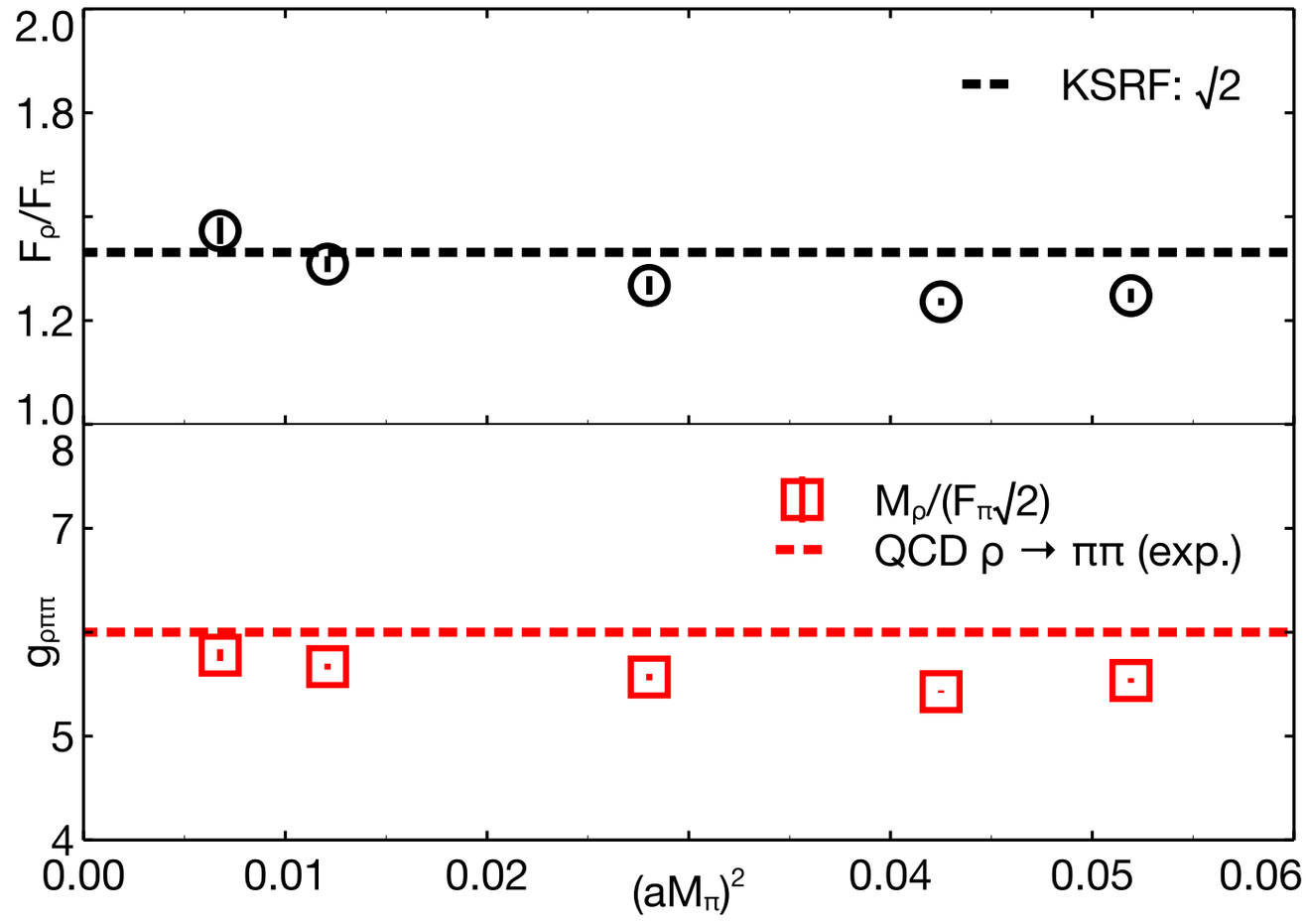
- KSRF relation can be used to estimate decay width of vector resonance, based on two assumptions:

  1) pi-pi scattering well approximated by LO chiPT.

  2) Vector meson dominance in pion vector form factor (in prog).

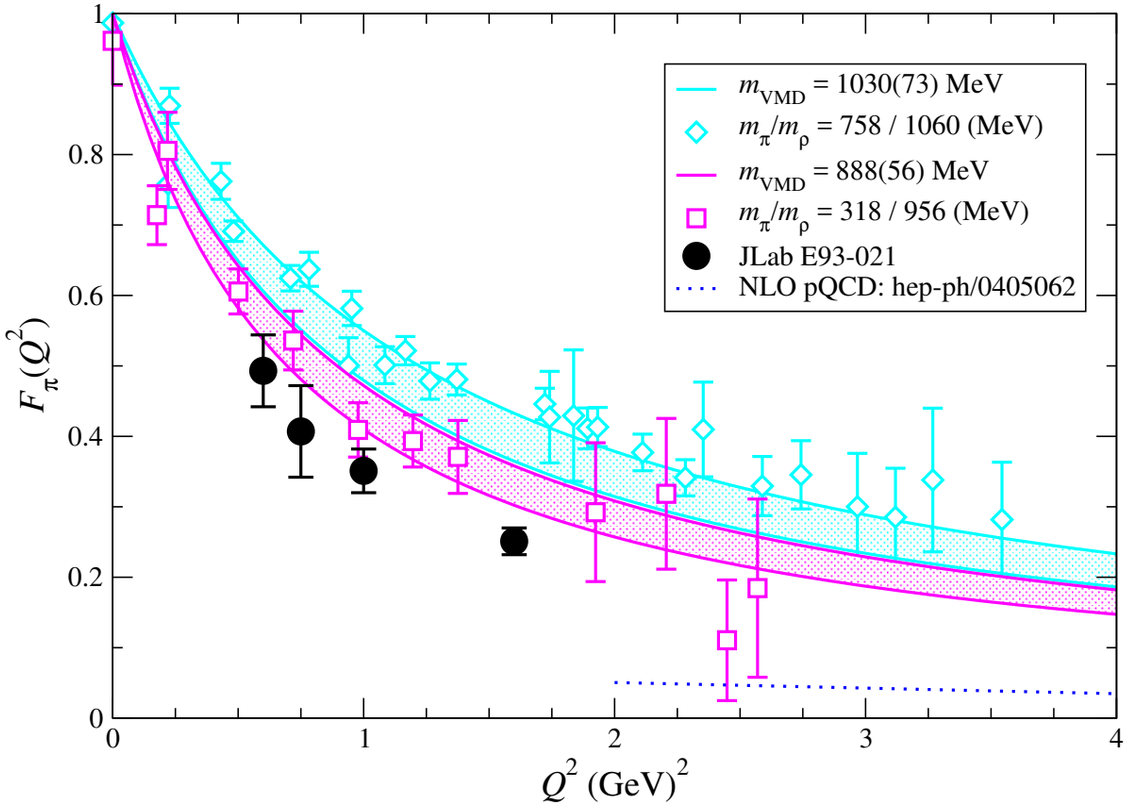
$$F_\rho = \sqrt{2}\, F_\pi \;, \quad g_{\rho\pi\pi} = \frac{M_\rho}{\sqrt{2}\, F_\pi} \;,$$

$$\Gamma_\rho \approx \frac{g^2_{\rho\pi\pi}\, M_\rho}{48\pi} \approx \frac{M^3_\rho}{96\pi F^2_\pi}$$

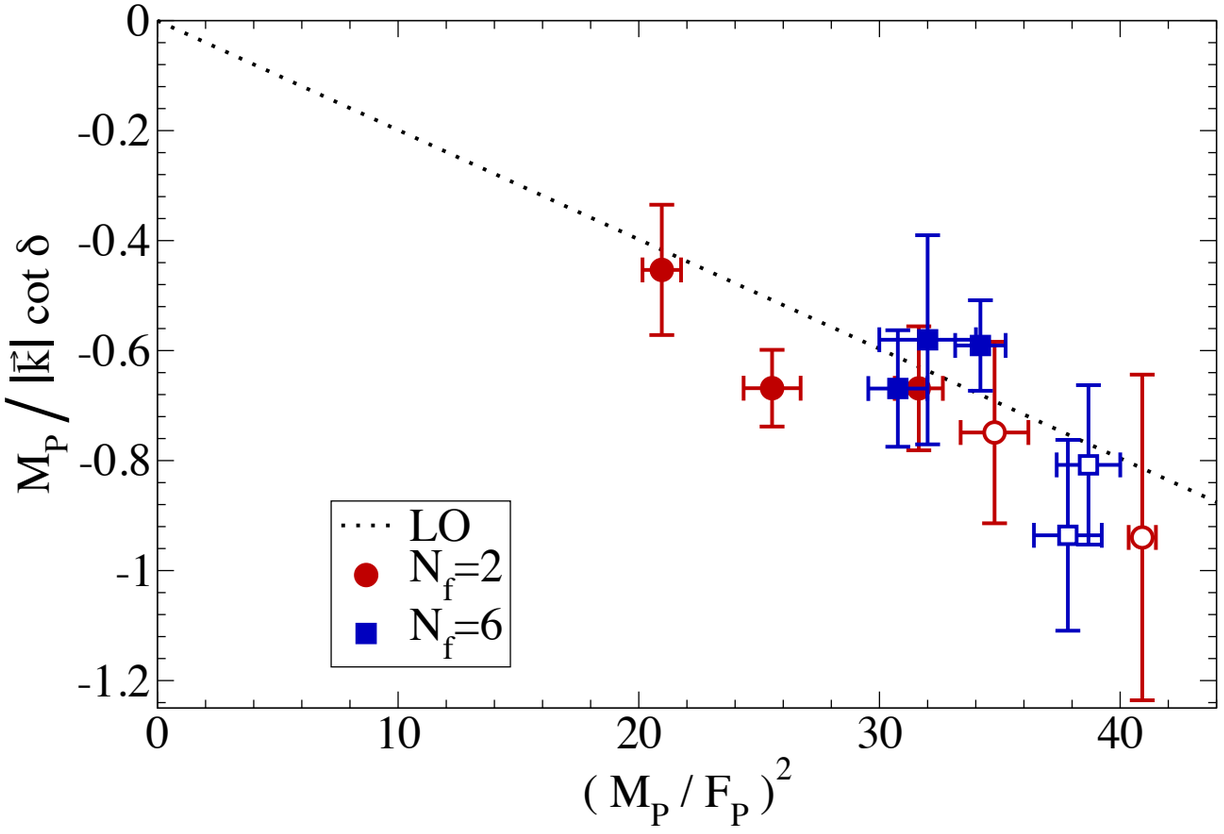


Why KSRF might hold when $M_\pi = 1/2\ M_\rho$

- pi-pi scattering in QCD is well approximated by LO chiPT even when $M_\pi >> F_\pi$.
- In QCD, VMD for pion form factor also holds for heavy pions.
- LSD has shown this is also true for $N_f=6$ for pi-pi scattering.



PRD 72, 054506 (2005)



LSD: PRD 85, 074505 (2012)

Composite Higgs Summary

- We now have clear examples of gauge theories with light scalars.

- Computing at masses $m_\pi \leq f_\pi$, where χPT might work, seems prohibitively expensive. So it's not clear how to extrapolate lattice results to chiral limit.

- I'm skeptical of various proposed EFTs for π-σ system since they don't include all possible interactions allowed by symmetry.

- Do the best we can to compute two particle scattering at accessible quark masses and see if it looks anything like the linear sigma model.

- I really wish I knew how the $f_0(500)$ mass and width in QCD depended on the quark mass. I hope someone will compute it soon.